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EMPIRICAL TREND ANALYSIS OF CLIMATE VARIABILITY IN EBONYI STATE, NIGERIA

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Abstract
This study assessed the trend in annual and seasonal temperature, rainfall, and relative humidity in Ebonyi State for the period 1997 to 2017 using time-series data collected from the Federal College of Agriculture, Ishiagu, in Ebonyi State. The analysis was carried out using the Non-parametric Mann-Kendall trend test, while the Sen's slope was used to estimate the magnitude of the changes. The results revealed significant increasing trends in annual and seasonal temperature. The mean annual temperature increased at a rate of 0.14°C annually, the rainy and dry season mean temperatures increased at the rate of 0.12°C and 0.13°C, respectively. The study found no significant trends for rainfall in the area during the period under study, decreasing at 0.43 percent per annum. Furthermore, the paper found a significant trend in mean annual relative humidity, but no significant trends in seasonal relative humidity.The results of this study are consistent with most studies in the South-East Nigeria, indicating that temperature is on the increase, with high volatility in rainfall and relative humidity. Hence, proper adaptation measures should be taken to address the impact of climate change in the study area.

Keywords: Rainfall, temperature, humidity, non-parametric trend analysis, Mann-Kendal, Sen's slope, and Ebonyi State

Introduction

Temperature and rainfall are important variables of climate change and variability (Asfaw, Simane, Hassen, and Bantider, 2018; IPCC, 2014a;IPCC, 2014b). Rainfall patterns shape flood and drought assessments and adaptation efforts, while temperature influences evaporation, transpiration and human and animal demand for water (Chattopadhyay and Edwards, 2016). Extensive scientific research has linked increased 'greenhouse' gases (GHG) in the atmosphere to increased global temperature (IPCC, 2014a). The upsurge in global temperatures has led to extreme hydro-climatic events with attendant socio-economic consequences (Ali, Kuriqi, Abubaker, and Kisi, 2019). Recently, increasing temperature has been linked with a further increased variability in the pattern of rainfall, which is a vital input in agricultural systems of developing countries (Amare, Jensen, Shiferaw, and Cissé, 2018; Ochieng, Kirimi, and Mathenge, 2016). Variability in the trends of climatic variables such as temperature, rainfall, and humidity have direct impacts on developing countries' agricultural systems—agriculture is seen to be very sensitive to slight changes in the climatic variables (Ali et al., 2019).

Smallholder producers are disproportionately affected by climate change as a result of the heavy reliance of agricultural activities on rain-fed conditions and low adaptive capacity of the farmers and farming systems (Asfaw et al., 2018; Ifejika-Speranza, 2010; Mereu et al., 2018). Recent climate variability is already posing a substantial challenge to Nigeria; like in most sub-Saharan African countries, temperature is expected to rise, while rainfall volume is generally expected to decline, while rainfall variability is expected to increase (Abiodun, Salami, and Tadross, 2011; IPCC, 2014b) in an environment of wide spread poverty and low development. Regional trends can, however, vary significantly from country-level observations because of terrain complexity and differences in atmospheric forces (Haag, Jones, and Samimi, 2019).

Due to rain-fed agricultural systems, low per capita land ownership, high land fragmentation, and decreased land productivity as a result of low soil fertility, increased rainfall variability, limited adaptive capacity, Ifeanyi-Obi et al. (2017), Merem et al. (2019) and Onyeneke (2020) identified Ebonyi State as among the important regions facing a high risk of climate variability and food insecurity. South-east Nigeria is situated largely on the rainforest agro-ecological zones in the country, and also currently affected by a changing climate (Ochege and Okpala-Okaka, 2017). Mean temperature in the region has been reported to be increasing, while there is increased variability in rainfall patterns. Several studies have reported that trend analysis of climatic variables is necessary for long-term mitigation and adaptation measures, particularly in rain-fed agricultural systems. It is important therefore, to analyze the trends in the major climatic variables in the region.

The literature on trend analysis of climatic variables, including trend detection depends on several statistical methods. Both parametric and non-parametric statistical techniques have been used in the analysis of trends and variability in climatic variables –' –(Chattopadhyay and Edwards, 2016; Gocic and Trajkovic, 2013; Mahmood, Jia, and Zhu, 2019; Ogunrinde, Oguntunde, Akinwumiju, and Fasinmirin, 2019). The parametric techniques require assumptions about the distribution of the climatic series. The least squares regression is a common parametric statistical technique, and typically requires a normally distributed series, however, this requirement is rare in climatic series (Mahmood et al., 2019). On the other hand, the non-parametric techniques require no strict distributional assumptions and are robust to extreme values. The most used non-parametric techniques include: Mann-Kendall test and Sen's Slope Estimator ' –(Haag et al., 2019; Mahmood et al., 2019; Ogunrinde et al., 2019). The non-parametric techniques are predominantly used in literature due to their simplicity and less restrictive requirements.

For agricultural activities, disaggregation of the annual and seasonal trends of climatic variables is very important for adaptation planning (Simane, Zaitchik, and Foltz, 2016; Asfaw et al., 2018). The potential scale of climate change impacts necessitates the analysis of trends of climatic variables to understand the nature of change and the probable impacts on livelihoods. Reliably estimating these trends is necessary for appropriate actions at the user and decision-making level. The objective of this study therefore, is to extend the existing literature by evaluating the trends in temperature, rainfall, and relative humidity in Ebonyi State, Nigeria.

Methodology

Study Area

The study was carried out in Ebonyi State, Nigeria. Ebonyi is one of the States in South-East Nigeria and located between 5°40' and 6°45'N and longitudes 7°30' and 8°46' (Onyeneke, 2020). The main livelihood in the State is agriculture, because majority of the populace depend on agriculture. The major seasons in the state are the rainy and dry seasons.

Data sampling procedure

Monthly time series of rainfall, mean temperature, and relative humidity from 1997 to 2017, were obtained from the weather station, located at the Federal College of Agriculture Ishiagu, Ebonyi State. The 21-year period from 1997 to 2017 was used for our study because it represents the maximum length of weather data available in the area.

Analytical procedure

Trend analysis of weather time series data require pre-check and test of serial correlation. The presence of serial correlation in the time series are corrected using a pre-whitening method before proceeding with the trend analysis —'(Gocic and Trajkovic, 2013; Mahmood et al., 2019; Obot, Chendo, Udo, and Ewona, 2010; Ogunrinde et al., 2019). Ignoring the serial correlation prior to trend analysis will result in incorrect estimates and increase in the probability of a Type 1 error (Chattopadhyay and Edwards, 2016; Gocic and Trajkovic, 2013). The serial correlation coefficient

$$r_1 = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}(x_i - \bar{X})(x_{i+1} - \bar{X})}{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{X})^2} \ldots\ldots\ldots\ldots (1)$$

The decision of the absence of significant serial correlation is made if the value of r falls within the bounds thus:

$$\frac{-1 - 1.645\sqrt{(n-2)}}{n-1} \le r_1 \le \frac{-1 + 1.645\sqrt{(n-2)}}{n-1} \ldots\ldots\ldots (2)$$

If, on the other hand, there is presence of significant serial correlation, pre-whitened series x with one less observation than the original series for subsequent analysis will be used. The form is stated thus:

$$x_i^* = x_{i+1} - r_1 x_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Trend Detection and Characterization

The literature on trend analysis of climatic variables, including trend detection, has benefitted from the application of several statistical methods. The broad classifications of these methods are parametric and non-parametric. The parametric methods typically assume a normal distribution for the series under study, while the non-parametric make no strict assumptions about the distribution of the series under study –(Mahmood et al., 2019; Ogunrinde et al., 2019). Due to the predominantly non-normally distributed and skewness of raw climatic and hydrologic data, the non-parametric analytical methods are recommended and widely used in the analyses of such data. In climatic, hydrologic and environmental applications, the non-parametric Mann-Kendall rank-based test is widely used to test the statistical significance of a monotonic trend in the mean of rainfall and temperature data –(Mahmood et al., 2019; Ogunrinde et al., 2019). The null hypothesis,

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(x_i - x_k) \ldots\ldots\ldots\ldots\ldots (4)$$

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$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_i - x_k) \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where sign is the signum function, nrepresents the sample size, whereas x and x are sequential data values in the series. The variance of S is calculated as follows:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k (t_k - 1)(2t_k + 5)}{18} \ldots\ldots\ldots \quad (5)$$

Where t_k defines the ties of the k^{th}value and m is the number of tied values, if the sample size n > 10 , the test statistic Z(S) is estimated as:

$$Z(S) = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & if\ S < 0 \end{cases} \ldots\ldots\ldots\ldots\ldots (6)$$

Where Z(S) values greater than zero and less than zero indicate increasing and decreasing trends respectively. Furthermore, if the absolute value of Z(S) is greater than the standard normal deviate or 1.64, at the specified α value (for example 5 percent or 0.05) in this study, the null hypothesis of no trend is rejected. Additionally, to quantify the magnitude of the trend in the time series, this study applies the Theil-Sen method. The advantage of the Theil-Sen method is that it yields more robust slope estimates than the parametric least-squares method due to less restrictive data distribution requirements and its consistency even in the presence of extreme values . Generally, we estimate the slope β of any two values of a series as:

$$Q' = \frac{x_k - x_j}{k - j}, k \neq j \quad \ldots\ldots\ldots\ldots\ldots (7)$$

Where Q' is the slope between the data points x_k and x_j; x_k is the data at time k and x_j is the data at time j. Using Sen's method, the overall slope of the data values is the median of the N values of Q' values. Thus, the overall slope estimator Q' is as follows:

$$Q' = \begin{cases} Q_{\frac{(N+1)}{2}}, N\ odd \\ \frac{Q_{\frac{(N)}{2}} + \beta_{\frac{(N+2)}{2}}}{2}, N\ even \end{cases} \ldots\ldots\ldots\ldots\ldots (8)$$

If the estimated trends are significant, Salmi et al. ' propose using non-parametric techniques to calculate the 95 percent confidence intervals, C_a, as follows:

$$C_\alpha = Z_{\frac{1-\alpha}{2}} \sqrt{Var(S)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where Z and Var(S) same as earlier described, and α is specified as 5 percent (0.05).

Results and Discussion

Temperature

Figures 2 through 4 show the trend plots of the annual and seasonal temperature time series from 1997 to 2017 in the study area. There is evidence of increasing trend in relative humidity over the period, with minimal inter-annual volatility. For the non-parametric analyses, Figures 11 through 13 shows the autocorrelation and partial autocorrelation plots of the total annual and seasonal temperatures. We can observe the absence of any significant autocorrelation in the series; hence, pre-whitening of the temperature series was not necessary. This study proceeds with estimating the base Mann-Kendall test of trend and Theil Sen's slope estimation. The annual and seasonal mean temperatures increased significantly in the area, showing a positive long-term trend, particularly in the mean annual temperature. Whereas the mean annual temperature increased at a rate of 0.14°C per year, the rainy season and dry season mean temperatures increased at the rate of 0.12°C and 0.13°C, respectively (Table 1).

Table 1: Linear trends of mean annual and seasonal temperature for Ebonyi State: 1997-2017

Time/ Season	Z-Value	Mann-Kendall Statistic (S)	Kendall's Tau	Var(S)	Sens's Slope	Confidence Interval	Test Interpretation
Annual	3.00	100	0.48	1090	0.141*	0.06 – 0.27	Reject H_0
Rainy	2.09	70	0.34	1092	0.121*	0.01 – 0.21	Reject H_0
Dry	2.79	92	0.46	1063	0.132*	0.03 – 0.29	Reject H_0

Note: * Indicates significance at the 5 percent Alpha (α) level

Source: Mann-Kendall test and Sen's slope method (including confidence intervals for Sen's slope, and z-statistics)

Relative Humidity

Figures 8 through 10 show the trend plots of the annual and seasonal relative humidity time series from 1997 to 2017 in the study area. We observed negative, but high volatility in annual and seasonal trends of relative humidity during the period. For the non-parametric analyses, Figures 17, 18, and 19 shows the autocorrelation and partial autocorrelation plots of the mean annual and seasonal relative humidity. We can observe the absence of any significant autocorrelation in the series; hence, pre-whitening of the relative humidity series was not necessary. This study proceeds with estimating the base Mann-Kendall test of trend and Theil Sen's slope estimation. The annual mean relative humidity decreased significantly in the area, showing a negative long-term trend. Conversely, the rainy and dry season relative humidity were negative, but did not show any significant long-term trend in Ebonyi State (Table 3). The annual mean relative humidity decreased by 0.43 percent per year, mostly due to the higher rainy season.

Table 2: Linear trends of total annual and seasonal rainfalls for Ebonyi State: 1997-2017

Time/ Season	Z-Value	Mann-Kendall Statistic (S)	Kendall's Tau	Var(S)	Sens's Slope	Confidence Interval	Test Interpretation
Annual	1.00	34	0.16	1096	8.38	-9.07 – +22.07	AcceptH_0
Rainy	0.75	26	0.12	1096	5.28	-11.14 – +19.74	Accept H_0
Dry	1.03	35	0.17	1095	1.80	-2.41 – +5.50	Accept H_0

Note: * Indicates significance at the 5 percent Alpha (α) level
Source: Mann-Kendall test and Sen's slope method (including confidence intervals for Sen's slope, and z-statistics).

Relative Humidity

Figures 8 through 10 show the trend plots of the annual and seasonal relative humidity time series from 1997 to 2017 in the study area. We observed negative, but high volatility in annual and seasonal trends of relative humidity during the period. For the non-parametric analyses, Figures 17, 18, and 19 shows the autocorrelation and partial autocorrelation plots of the mean annual and seasonal relative humidity. We can observe the absence of any significant autocorrelation in the series; hence, pre-whitening of the relative humidity series was not necessary. This study proceeds with estimating the base Mann-Kendall test of trend and Theil Sen's slope estimation. The annual mean relative humidity decreased significantly in the area, showing a negative long-term trend. Conversely, the rainy and dry season relative humidity were negative, but did not show any significant long-term trend in Ebonyi State (Table 3). The annual mean relative humidity decreased by 0.43 percent per year, mostly due to the higher rainy season.

Table 3: Average Statistics of relative humidity trend analysis results for Ebonyi State:1997-2017

Time/ Season	Z-Value	Mann-Kendall Statistic (S)	Kendall's Tau	Var(S)	Sens's Slope	Confidence Interval	Test Interpretation
Annual	-2.08	-70	-0.33	1096	-0.43*	-0.79 – +0.02	Reject H_0
Rainy	-1.42	-48	-0.23	1092	-0.23	-0.72 – +0.09	Accept H_0
Dry	-0.09	-4	-0.02	1094	-0.05	-0.75 – +0.48	Accept H_0

Note: * Indicates significance at the 5 percent Alpha (α) level

This study shows a general increase in temperature in the study area within the period. Significant increase in annual and seasonal temperatures has been identified in previous studies, however with different trend magnitudes (Abiodun et al., 2011; Chikezie et al., 2016; Diagi and Weli, 2017; Onyeneke, Mmagu, and Aligbe, 2017). Our results showed an annual temperature increase of 0.14 °C per year within the period, compared to the study of Diagi and Weli (2017) and Onyeneke *et al.* (2017) who indicated an annual temperature increase of 0.0037°C per year (1984-2015) and 0.03°C per year (1972-2012). According to our results, dry season temperature indicates a higher temperature (0.13 °C per year), as expected, than the rainy season temperature (0.12 °C per year).

Rainy season is an important season in Nigerian agricultural systems because most of the annual rainfalls occur during that time, and water storage and management activities are maximized (Onyeneke et al., 2017). Variable rainfall patterns during this season can lead to water shortages in the dry season and adversely affect crop yields (Onyeneke, ibid). However, our results do not indicate any significant changes in rainfall during the period under study. Rainfall exhibited unsteady rise and fall in trend patterns during the period under, hence no significant trend was recorded. Our result is consistent with Nwaiwu *et al*. (2014), who found an increasing, but insignificant trend in rainfall in the South-East region but agrees with Onyeneke *et al*. '(2017) who found high inter-annual variability in rainfall, hence insignificant rainfall trend. Conversely, it differs from other studies in other towns of the South-East (where Ebonyi is located); Onyeneke *et al*. –(2020) indicated an increasing trend for rainfall in the South-East region of Nigeria which comprise mainly the tropical rainforest from the period 1961 to 2016, while Oloruntade, Mogaji, and Imoukhuede (2018) noted a decreasing trend in annual rainfall in Onitsha, Anambra State from 1971 to 2008 period. Finally, this study finds evidence of decrease in mean annual relative humidity in the study area since 1997, with a decrease of 0.43 percent per annum. However, rainy season and dry season show negative, but insignificant trends. These different results can be linked to the observed high volatility in the trend of relative humidity over the period. Chikezie *et al*. (2016)found a negative but insignificant trend for relative humidity in South-East Nigeria during the 1984-2014 period.

Conclusion

This study estimated trends in the annual and seasonal temperature, rainfall, and relative humidity in Ebonyi State, Nigeria from the period 1997 to 2017. The highest significant increase in annual temperature was estimated, with an increase of 0.14°C. The positive long-term trend in temperature indicates that relevant authorities should take necessary action to adapt to climate change in the area. The trend in mean annual relative humidity increased significantly, while the seasonal relative humidity was not significant. While this study used appropriate observational data, the accuracy of the results may be limited by the missing long-term records. However, the data used in this study represents the longest recorded weather data in the town. However, a good understanding of weather and climatic change in the study area is important because of the subsistence agriculture-based and natural-controlled lifestyle of the rural communities. The findings of the study can be beneficial for agricultural adaptation planning and policies in Ebonyi and other areas with similar socio-economic and climatic conditions. There is need therefore, to encourage planting of heat resistant-crops, increasing farm water management practices due to higher risk of evaporation from increasing temperature.

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Appendix A: Temperature Trend Plots

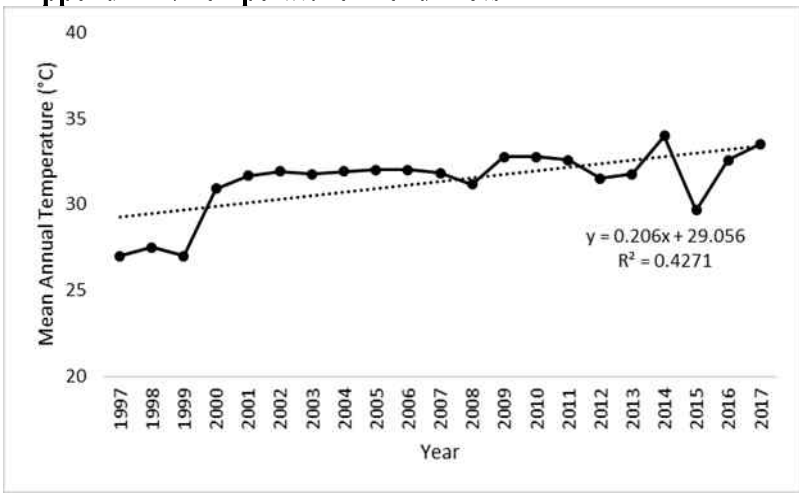


Figure 1: Mean Annual Temperature in Ebonyi State, 1997 -2017

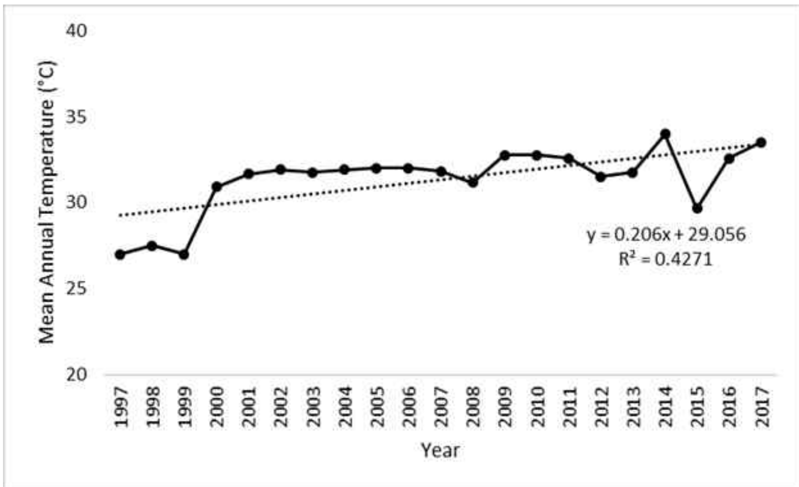


Figure 2:Mean Annual Temperature in Ebonyi State, 1997-2017

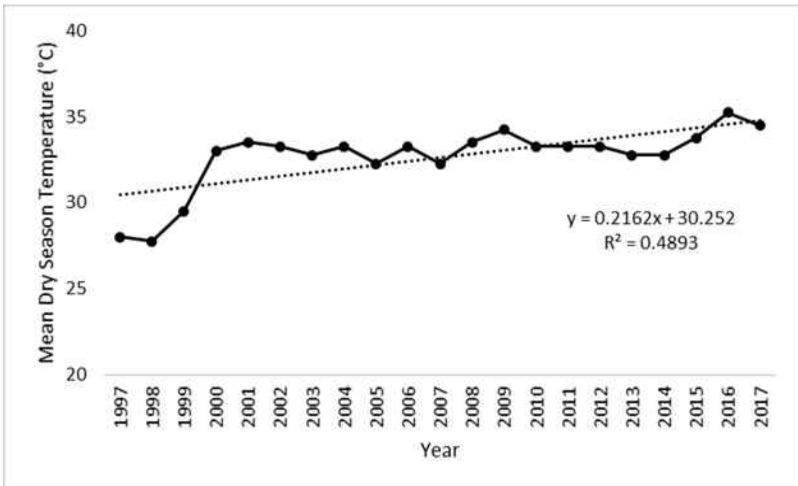


Figure 3: Mean Rainy Season Temperature in Ebonyi State, 1997-2017

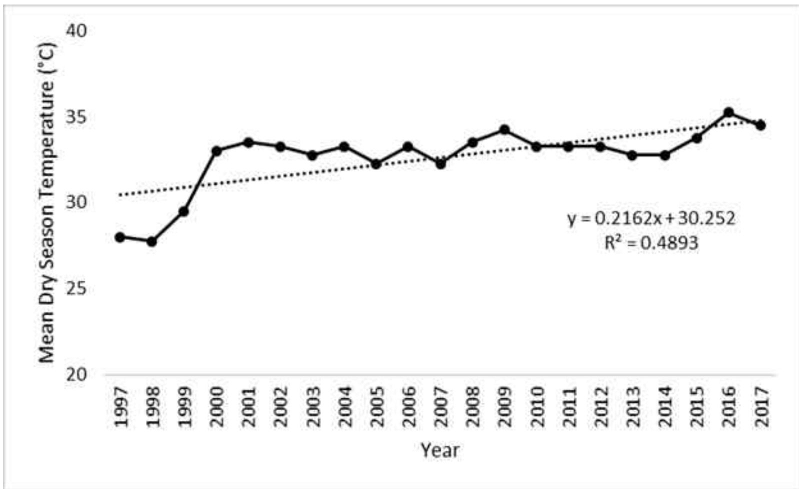


Figure 4: Mean Dry Season Temperature in Ebonyi State, 1997-2017

Appendix B: Rainfall Trend Plots

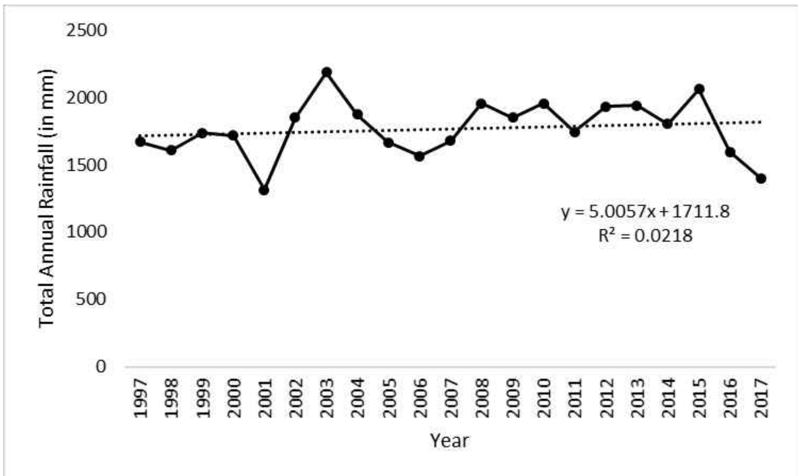


Figure 5: Total Annual Rainfall in Ebonyi State, 1997-2017

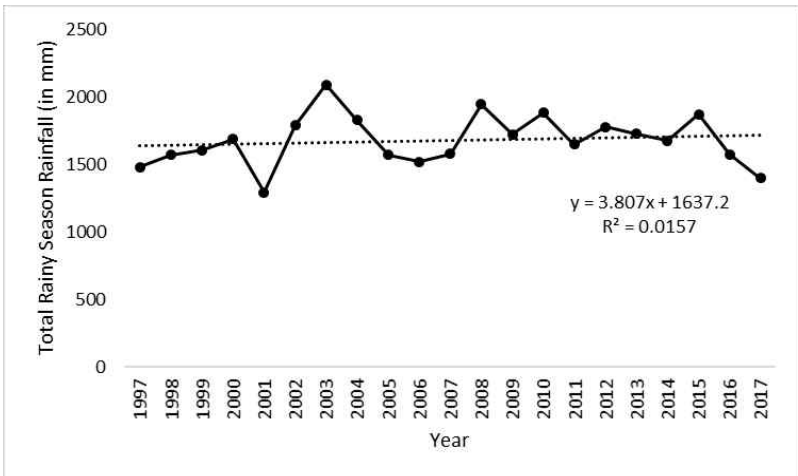


Figure 6: Total Rainy Season Rainfall in Ebonyi State, 1997-2017

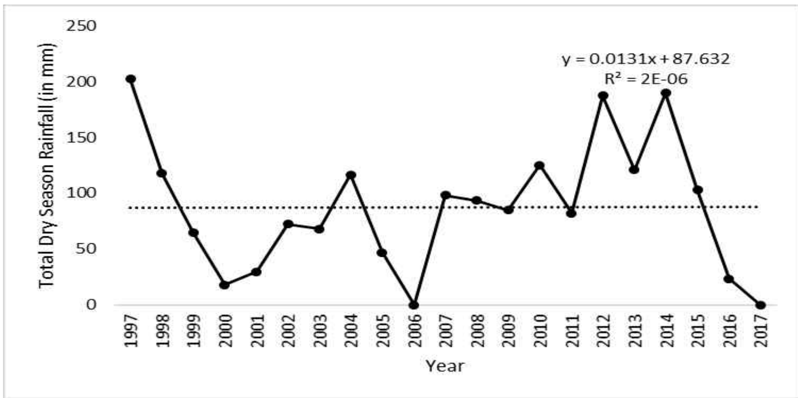


Figure 7: Total Dry Season Rainfall in Ebonyi State, 1997-2017

Appendix C: Relative Humidity Trend Plots

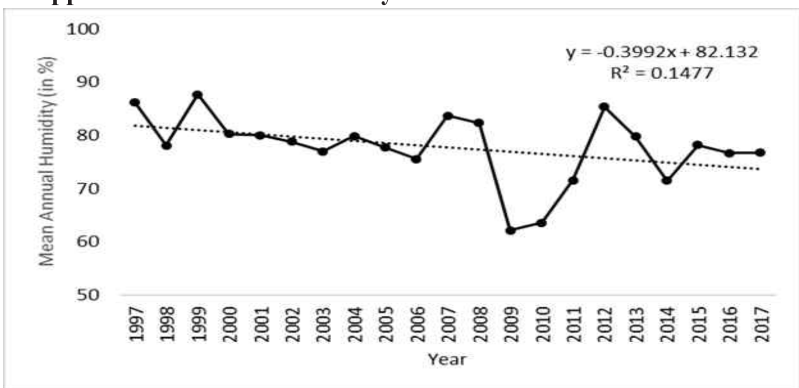


Figure 8: Mean Annual Relative Humidity in Ebonyi State, 1997-2017

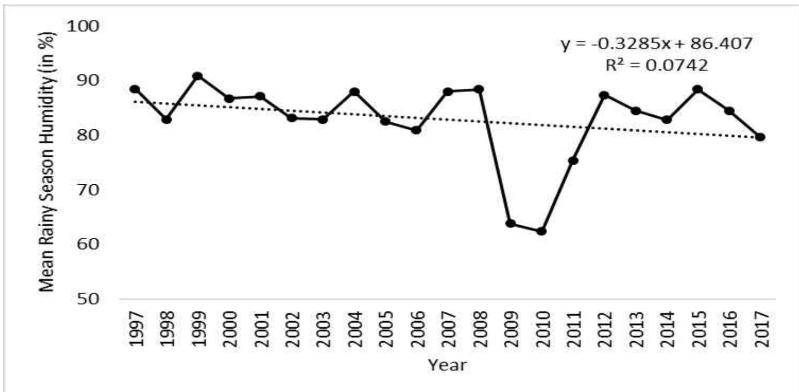


Figure 9: Mean Rainy Season Relative Humidity in Ebonyi State, 1997-2017

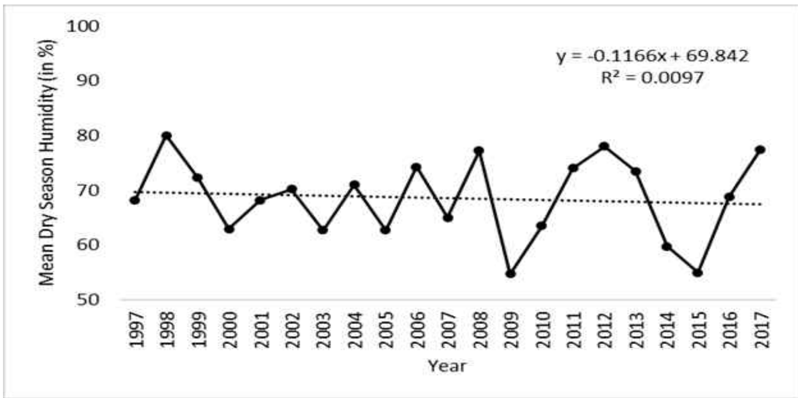


Figure 10: Mean Dry Season Relative Humidity in Ebonyi State, 1997-2017

Appendix D: Autocorrelation and Partial Autocorrelation Plots

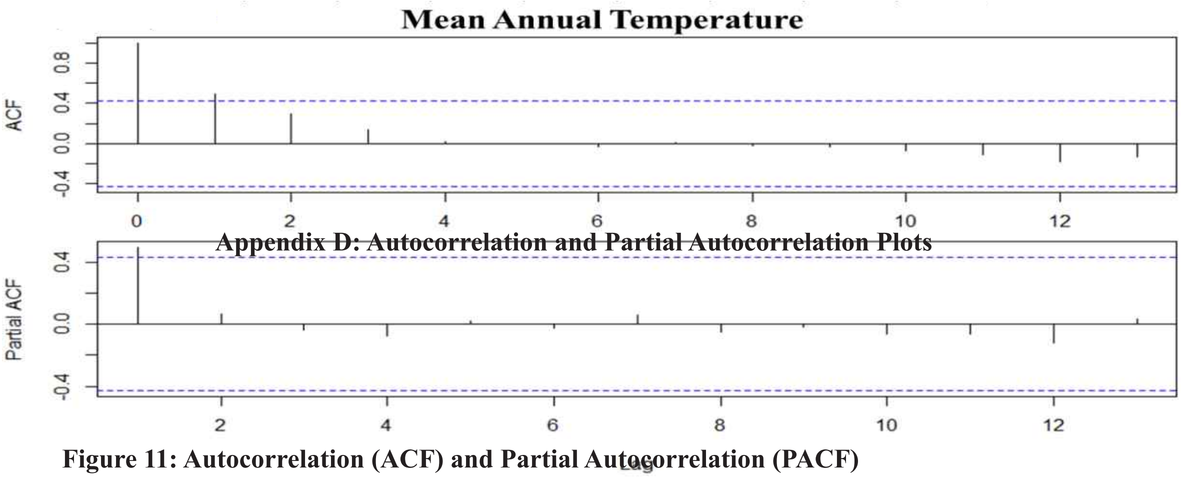


Figure 11: Autocorrelation (ACF) and Partial Autocorrelation (PACF) Plot of Mean Annual Temperature in Ebonyi State, 1997-2017

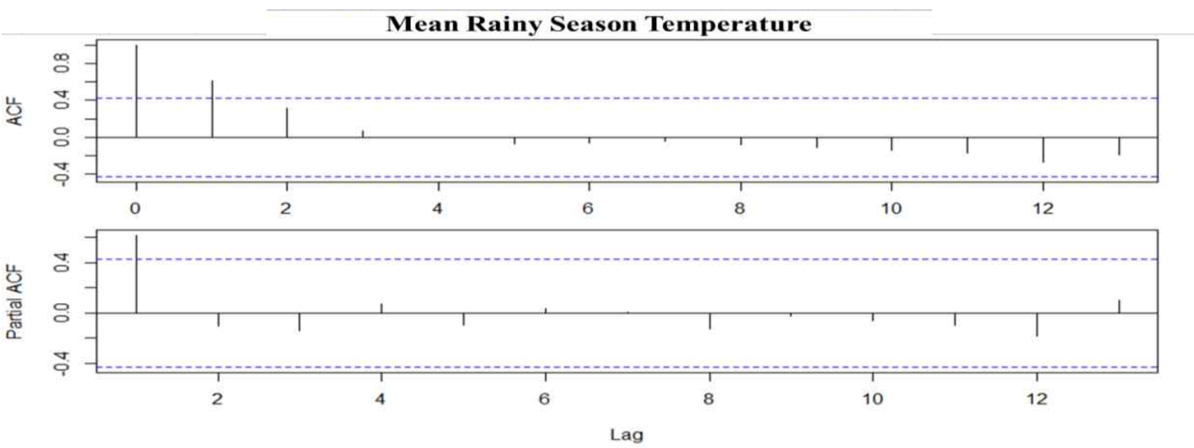


Figure 12: Autocorrelation (ACF) and Partial Autocorrelation (PACF) Plot of Mean Rainy Season Temperature in Ebonyi State, 1997-2017

Appendix E: Autocorrelation and Partial Autocorrelation Plots

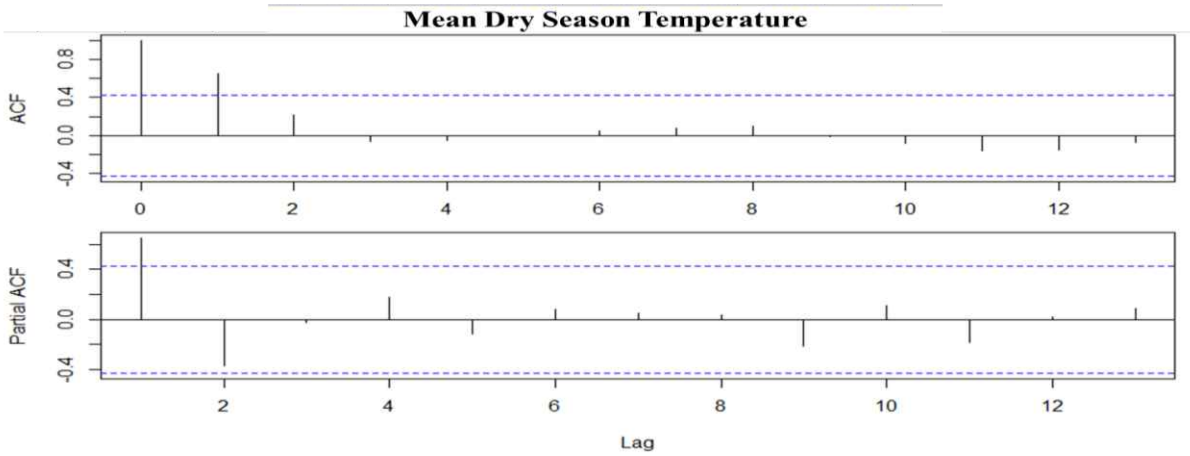


Figure 13: Autocorrelation (ACF) and Partial Autocorrelation (PACF) Plot of Mean Dry Season Temperature in Ebonyi State, 1997-2017

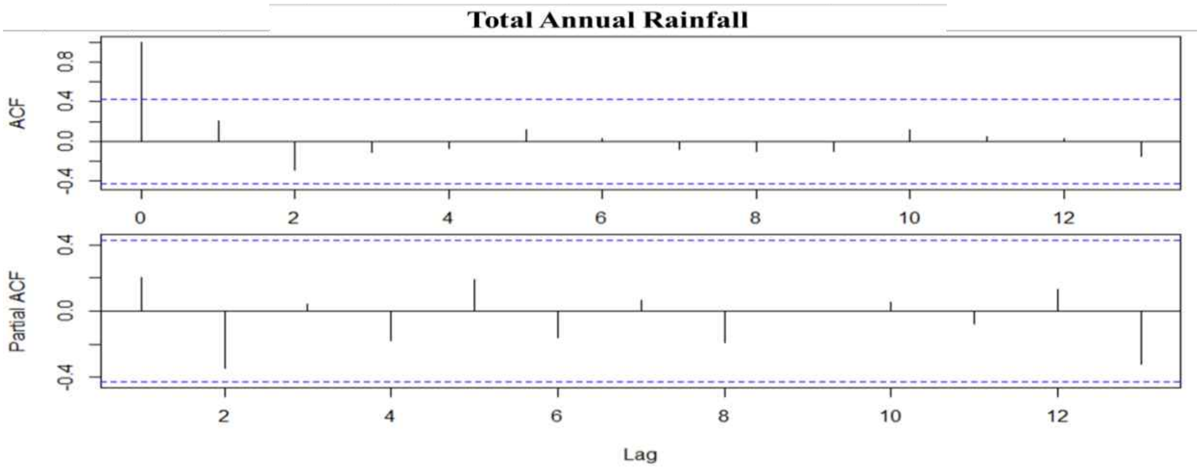


Figure 14: Autocorrelation (ACF) and Partial Autocorrelation (PACF) Plot of Total Annual Rainfall in Ebonyi State, 1997-2017

Appendix F: Autocorrelation and Partial Autocorrelation Plots

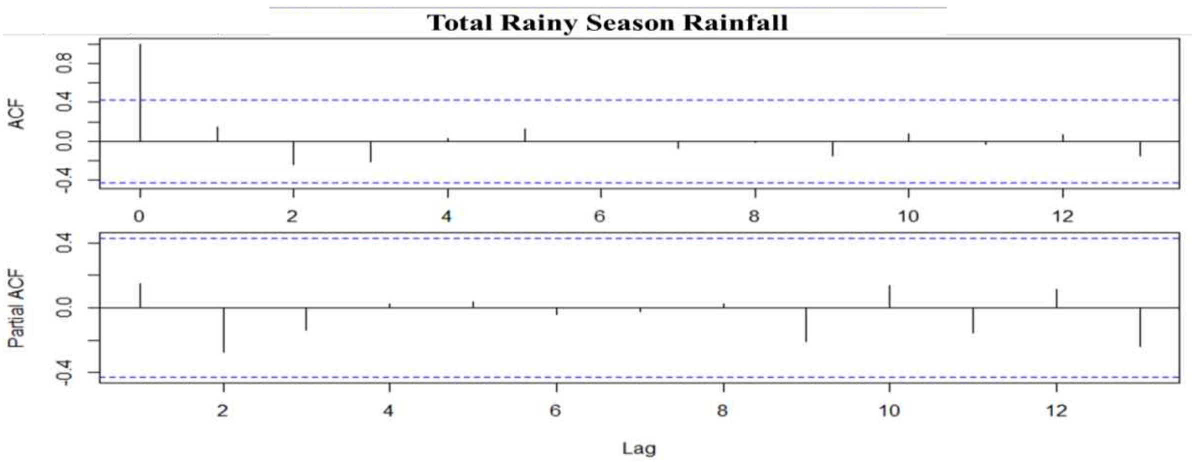


Figure 15: Autocorrelation (ACF) and Partial Autocorrelation (PACF) Plot of Total Rainy Season Rainfall in Ebonyi State, 1997-2017

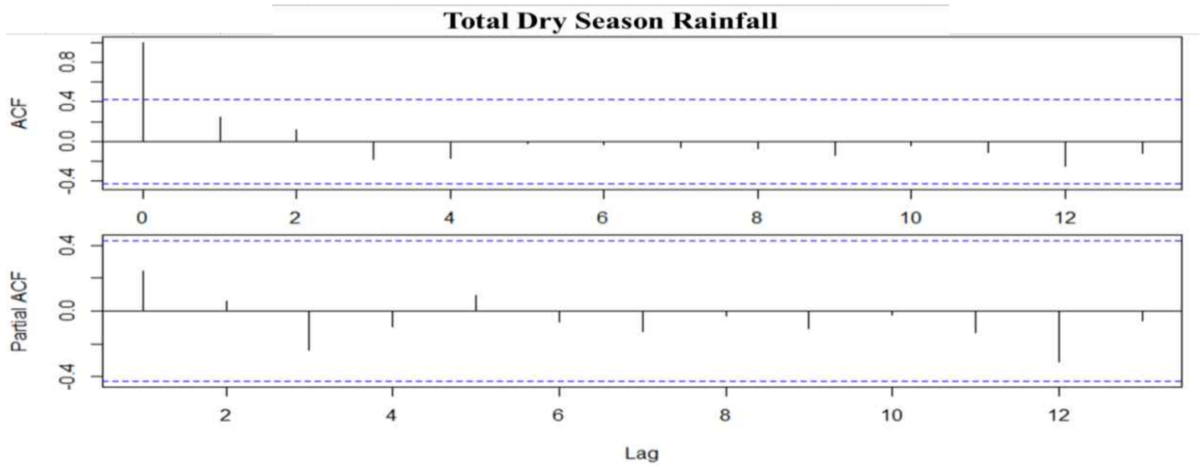


Figure 16: Autocorrelation (ACF) and Partial Autocorrelation (PACF) Plot of Total Dry Season Rainfall in Ebonyi State, 1997-2017

Appendix G: Autocorrelation and Partial Autocorrelation Plots

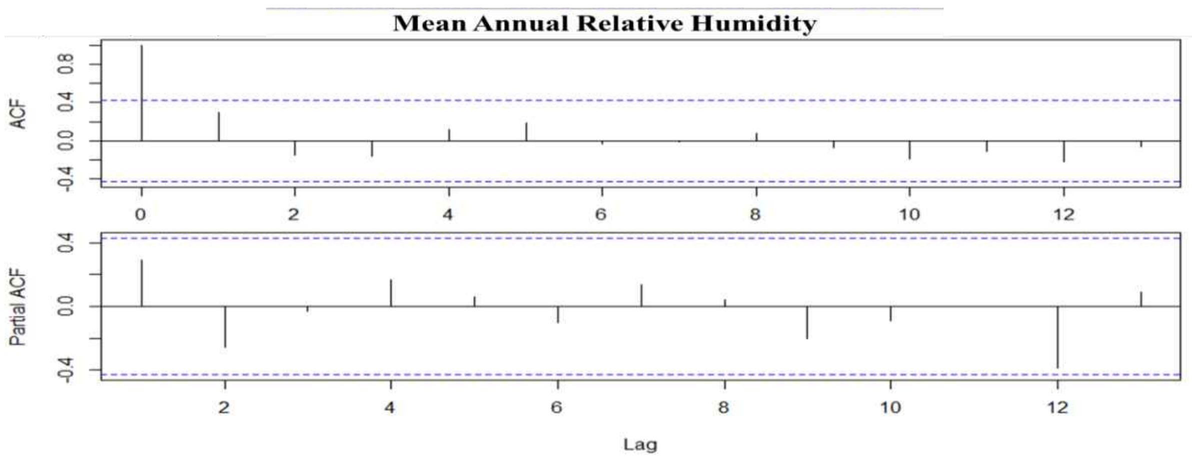
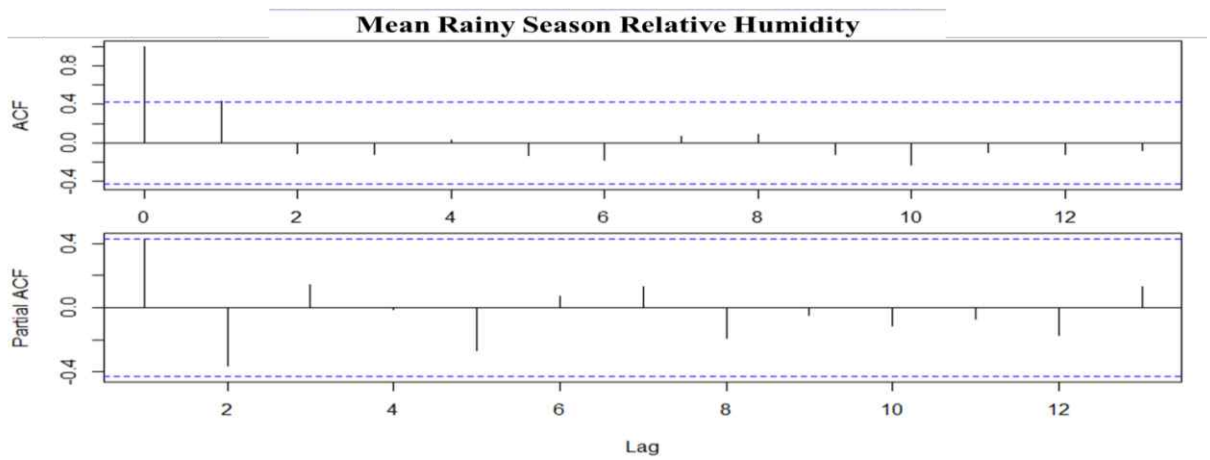


Figure 17: Autocorrelation (ACF) and Partial Autocorrelation (PACF) Plot of Mean Annual Relative Humidity in Ebonyi State, 1997-2017



18: Autocorrelation (ACF) and Partial Autocorrelation (PACF) Plot of Mean Rainy Season Relative Humidity in Ebonyi State, 1997-2017

Appendix H: Autocorrelation and Partial Autocorrelation Plots

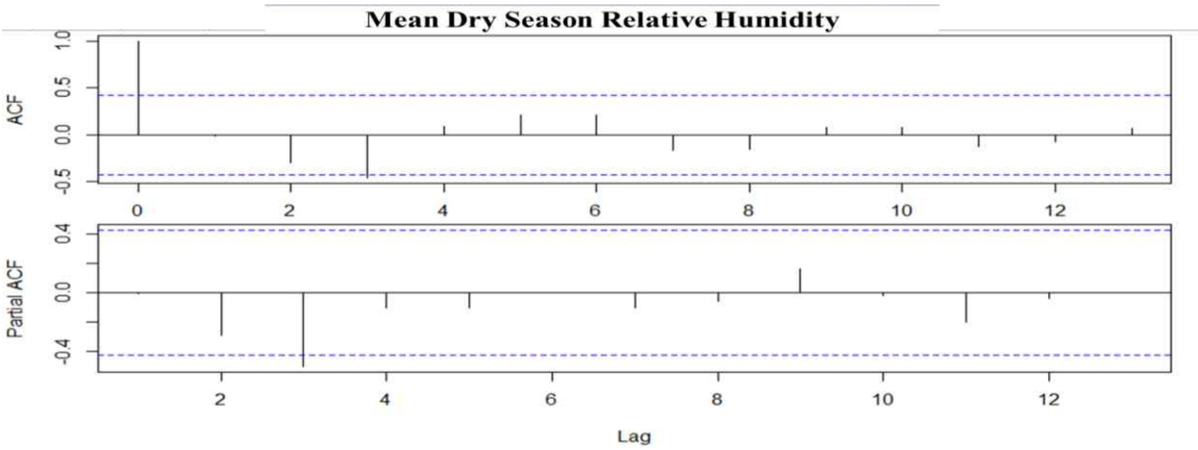


Figure 19: Autocorrelation (ACF) and Partial Autocorrelation (PACF)
Plot of Mean Dry Season Relative Humidity in Ebonyi State, 1997-2017